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Physiography as an integral part of forest ecosystems

D BURGER
Ontario Tree Improvement and Forest Biomass Institute, Ontario Ministry of Natural Resources, Maple, Ontario, Canada

Abstract
Forestry is active at local, regional, national and continental levels, and uses knowledge and understanding of the distribution and dynamics of forest ecosystems, the vegetation/soil/climate complexes which are the primary production systems.

This paper outlines the principles and relevance of a site classification system or model, in which selected physiographic features of soil and climate provide a relatively stable framework for considering the more dynamic vegetation/land relationships both in space and time. Significant characteristics of this system are forest succession in relation to physiography, feature continua, normality rather than average as a reference criterion in such continua, and also the establishment of classes within continua by concurrent reference to vegetation rather than *a priori*. The selected features of local climate, soil moisture regime and soil nutrient regime are related to more easily recognizable features of the landscape.

The classification comprises 4 inter-related levels, with increasing differentiation and detail of feature classes. They include (climatic) site or ecoregion based on differing relationships among tree species and position in the landscape, relevant geological material classes in the rooting zone of trees, physiographic site type being the stable basis of the ecosystem at the practical level of forestry operations, and, finally, site condition comprising the more variable surface soil and ground vegetation.

This hierarchical system, developed in Ontario, Canada, during the past 40 years, is valuable for interdisciplinary research, for evaluating relative productivity, for management planning at various levels of complexity, and for information transfer, even among widely separated areas.

1 Introduction
Forest management – being part of land management – is engaged in the manipulation of ecosystems at various levels of complexity, ie from planting a crop on a specific site, to management of large tracts of land, to national policy development. To be most effective, the management planning and operations at the various levels should be inter-related in an ecological framework so that decisions made at one level are compatible with those at other levels. The development of this framework requires a knowledge of ecosystems, their composition, their distribution and their dynamics.

The forest ecosystem is a dynamic complex of interacting and inter-related biotic and abiotic factors or subsystems. Forest managers must consider both the vegetation and the important soil and other physical environmental factors. Without an understanding of this complex ecosystem, we can exploit the forest but not manage it as a crop towards renewed and improved production.

Once we acquire knowledge of local ecosystems, through scientific investigations and by experience gained during management practices, we must organize it within a classification framework of ecosystem types, based on an appreciation of cause/effect relationships, ie how various factors affect the performance of tree species. This procedure allows the forest manager to select, consider and use only the relevant knowledge and experience from previously treated areas, when making new decisions about treating another specific area. The most relevant knowledge comes from ecosystems of the same type as that about to be treated.

For purposes of classification to facilitate the transfer of management knowledge, scientists and managers have used information on factors such as climate, topography, geology, land form, soil, flora and fauna, sometimes separately with the intent to combine these various factors at a later stage. However, we must remember that the relevance of any one factor for tree growth depends on the combined effect of all other factors. For example, in a humid region, tree growth on a clay soil may be better than on sand, but, in a more arid region, trees may grow mainly on the sandy soils while the clay soils support grass. Tree species usually have a considerable range of distribution, but within this range their occurrence and vigour in relation to specific land form features, such as slope position and aspect, as well as soil drainage, vary considerably. This variation reflects a compensation among climate and soil factors.

Because the significance of the variation in any one factor is dependent upon the total effect of all the other factors in the ecosystem complex, it is logical to approach the evaluation of the relevance of factors through a classification of ecosystems as a whole.

Such an integrated approach has been developed for Ontario by Hills (1952, 1960, 1976) and a team of researchers (see Burger 1972b). It has resulted in a hierarchical system originally oriented towards forestry, but later broadened to provide an ecological basis for land use planning, including uses other than timber production. The system has 4 inter-connected levels, based on an increasing completeness in considering the detail of ecological relationships.

The purpose of this paper is to describe how the Ontario classification system integrates knowledge of vegetation, soil and climate to provide an ecological framework which is useful for the management of forest ecosystems.

2 Concepts and principles

Forest management requires the management of an ecosystem, the whole local biological production system, which Hills (1953) has also called 'total site' or just 'site'. The general approach used in this classification of 'total sites', or ecosystems, is based on the principle that, although ecosystems include all environmental features, they may be classified by a single feature or by a combination of features (Hills 1953), depending on the purpose. In Ontario, that purpose was to provide an ecological basis for forest management for an area about the size of north-east China or of France and Spain together, within which ecosystems range from northern tundra to deciduous broadleaved forests in the south.

Because ecosystems are dynamic systems, physiographic features have been chosen to constitute the logical frame of reference, because these features remain most stable in a world of constant change (Hills 1952).

Three physiographic features which directly affect plant growth have been chosen. They include:

- — ecoclimate regime, which refers to the variations in the atmosphere (effective temperature and effective humidity) of local areas between ground surface and tree tops;
- — soil moisture regime, which refers to the soil moisture supply during a complete vegetation cycle;
- — soil nutrient regime, which refers to nutrients available in the rooting zone of trees.

These 3 features are related to readily observable features in the landscape, namely relief (slope, aspect, relative mass elevation and relative position of bodies of water), soil pore size distribution pattern (combinations of soil texture and structure), and mineral composition of soil materials.

Used in combination, these features comprise the so-called physiographic site, which is the most stable component of the local forest ecosystem.

The relative level of each of these features – ecoclimate, soil moisture and soil nutrient regime – is ranked during field investigations on the 11-class scale, covering the complete continuum from extremely low (θ) to extremely high (9) as follows:

θ, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

For some management purposes, these 11 classes have been grouped into broader classes. Thus, for example, the soil moisture regime scale in Ontario ranges from 'extremely dry' (θ) to 'saturated' (9), with broader groupings: 'dry' (θ,0), 'fresh' (1,2,3), 'moist' (4,5,6) and 'wet' (7,8,9).

As an important reference point, Hills (1945) applied the term 'normal' as used by Marbut (1927) in his concept of normal soil profile development. Normal does not equal average, modal, or optimum, but, instead, it is a standard well-defined reference point. On the above-mentioned continuum scale, the normal is positioned somewhere near the middle to provide adequate numbers of classes on both sides to suit the above purpose. Thus, a 'normal physiographic site' has a normal ecoclimate regime, a normal moisture regime and a normal soil nutrient regime. The primary land form reference point is a gently undulating, well-drained deep loam, with no significant deficiencies or excesses of nutrients, and a gently undulating topography which imparts no extreme influence on the ecoclimate. This is a useful practical reference point during field investigations. On such a normal physiographic site, vegetation development reflects the unmodified effectiveness of the macro- (or regional) climate. Thus, in a humid region, the normal site provides adequate moisture for a mesophytic vegetation, but, in an arid region, only xerophytes can survive on the normal site.

On any one physiographic site, vegetation is not stable. Given the opportunity, it tends to develop in a succession from a pioneer stage through intermediate stages to a climax or least disturbed stage. A pioneer vegetation type – as characterized by its tree species – may occur over a considerable range of physiographic sites within one climatic region, and even across 2 or more regions, whereas a climax vegetation has a more restricted range.

When relating forests to physiographic sites, Hills (1960) argues that neither physiographic nor biotic types can be established independently, but that groups of features must be classified concurrently. Forest types are often established independently, on

the assumption that similar forests have similar environmental controls, but that assumption does not take into account the compensation of factors. Similarly, independent classification of climate or soil is not adequate either, as these are only one portion of the total productivity complex.

The above principles were used in the development of a hierarchical physiographic classification system comprising 4 inter-related levels; they include, from the broad to the local level, site region, land type, physiographic site type and site condition.

3 Site regions

It is well recognized that vegetation changes with latitude within a continent, and changes with altitude at a given latitude, such as on a mountain. For example, on Mount Washington in the White Mountains of the State of New Hampshire, USA, using the physiognomy of the vegetation, one can easily recognize 4 vegetation zones, from deciduous forest to alpine tundra, over an approximately 1.5 km range in altitude. The distance from the base of this mountain to the comparable subarctic zone in the north is about 1300 km. For a similarly great latitudinal distance in Ontario, Rowe (1972), using physiognomy and the presence of some tree species as criteria, recognized 4 forest regions. However, over that great distance with a relatively low relief, changes occur not only in the physiognomy and tree species occurrence, but also particularly in the relationships between species and physiography which are relevant to forest management. In site regions, we recognize such particular changes, and 6 site regions have been distinguished in the above south–north Ontario example.

Site regions in Ontario are defined as regions within which specific plant successions occur upon specific land form positions. Conversely, similar land forms (relief and geological materials) within different site regions will support different plant successions. The different vegetation/land form relationships in various site regions are a reflection of differences in regional climate (Hills & Pierpoint 1960).

The characterization of any one site region in Ontario can be demonstrated on a simple grid (Table 1)

Table 1 The 'grid' of 9 physiographic sites which provide the basis for the characterization of vegetation/site relationships in site regions of Ontario

		Ecoclimate regime		
		Hotter	Normal	Colder
Soil moisture regime	Drier			
	Normal			
	Wetter			

comprising 2 continua, namely ecoclimate (ie effective local temperature as influenced by local topographic position) and soil moisture (as influenced by soil materials and local drainage conditions). The characterization is based mainly on the most stable vegetation type on the normal physiographic site type, plus the most stable vegetation type on each of the 8 important deviations from the normal. In addition, the less stable (pioneer and intermediate) types indicate successional trends. These relationships have been published by Hills (1950, 1966, 1976) and Burger (1976). Table 2 demonstrates how, for the same normal moisture regime but with 3 different ecoclimates (temperature only) – ie normal, hotter than normal and colder than normal – 3 species (*Picea glauca* (Moench) Voss (white spruce), *Acer saccharum* H. Marsh. (sugar maple) and *Carya ovata* (Mill.) K. Koch (hickory)) change their preferred positions in the 7 most eastern site regions in Ontario, trending north to south. With these changes, there are also related changes in the vigour of other tree species, ecosystem productivity, and type of ground vegetation which competes with forest regeneration. Shifts such as those shown here for macroclimatic temperature gradients occur also in the east–west air humidity gradient. Similarly, humidity-related shifts are very likely important in north-east China, as well as any temperature-related shifts.

Table 2 Change of preferred positions of 3 tree species on the normal moisture regime, but with 3 different ecoclimates for the 7 most easterly site regions of Ontario

	Ecoclimate		
Site region	Hotter	Normal	Colder
1E	P		
2E	P	P	
3E	P	P	
4E	A P	P	
5E	A	A	P
6E	C	A	P
7E		C A	

P = *Pica glauca*; A = *Acer saccharum*; C = *Carya ovata*

In site regions, we have thus placed ecosystems in a macroclimatic context or continental continuum. These regions could be called gradient-defined regions, and differ from the original geographical regions which can be called areal-described regions (Hills 1960). Both are important for the distribution of knowledge; their functions, however, differ.

The concept of site regions was developed in Ontario to recognize important gradients in species/site relationships over long distances where altitudes range mainly from 0 m to 500 m. In mountains with greater ranges in altitude, forest zones have been recognized. It seems quite possible that the concept of site regions could be applied within such altitudinal zones, particularly in such mountains as in north-east China and the eastern USA, where there is a strong north–south trend, and where altitudinal zones occur as high plateaux rather than as steep mountain slopes.

For the characterization of site regions, knowledge is required of the distribution of tree species in relation to land form positions, ie physiographic site types; for mapping these regions, information on distribution ranges of tree species, climatic gradients, relief, soil and geology is very useful. Where vegetation has been severely disturbed, remnants of ecosystems, or scattered occurrences and performance of individual forest trees or domesticated fruit-bearing trees may offer clues regarding important regional gradients. Historical records would also be valuable.

The boundaries of site regions are based on the manner in which more than one species adapt themselves to the gradients in the macroclimate. No 2 species act in exactly the same manner, but many show similarities. Regional boundaries are therefore transition zones; they are not sharp, but serve as warning signs that relationships between species and sites are changing, the closer the boundary is approached. Sometimes the boundaries are fairly sharp where the physiography changes abruptly. Furthermore, in Ontario, boundaries based on north–south temperature gradients are somewhat more easily recognizable than those indicating the east–west air humidity gradients.

It should be realized that the soil moisture continuum in a moist climate will differ in absolute terms from one in a dry climate, although the same 11 class scale (0–9) can be used. The concept of 'normal' is the same for all regions; in a humid region, the normal may be called fresh, ie suitable to support a mesophytic forest, but in a dry climate the normal is much drier, with the optimum site for mesophytes occurring in a lower position in the topography. Moisture regime ratings are thus specific for each site region. The use of a universal moisture regime scale has been discussed by Hills (1952).

Figure 1 and Table 2 show and characterize the 13 site regions of Ontario. Beyond Ontario, preliminary site regions have been recognized in the lake states of the USA (Burger 1976); the term 'forest ecosystem region' was proposed, because ecosystem is synonymous with 'total' site, and because ecosystem region might be a more convenient term for international, and perhaps intercontinental, communication than 'site region'. Studies to characterize and map such regions covering all of Canada and eastern USA are in progress.

4 Land type, physiographic site type and site condition
Within site regions, the classification system recognizes 'land type' as the second level. This is defined in terms of taxonomic classes of texture and petrography of geological materials which occur within the normal rooting depth of trees (Hills & Pierpoint 1960). To be

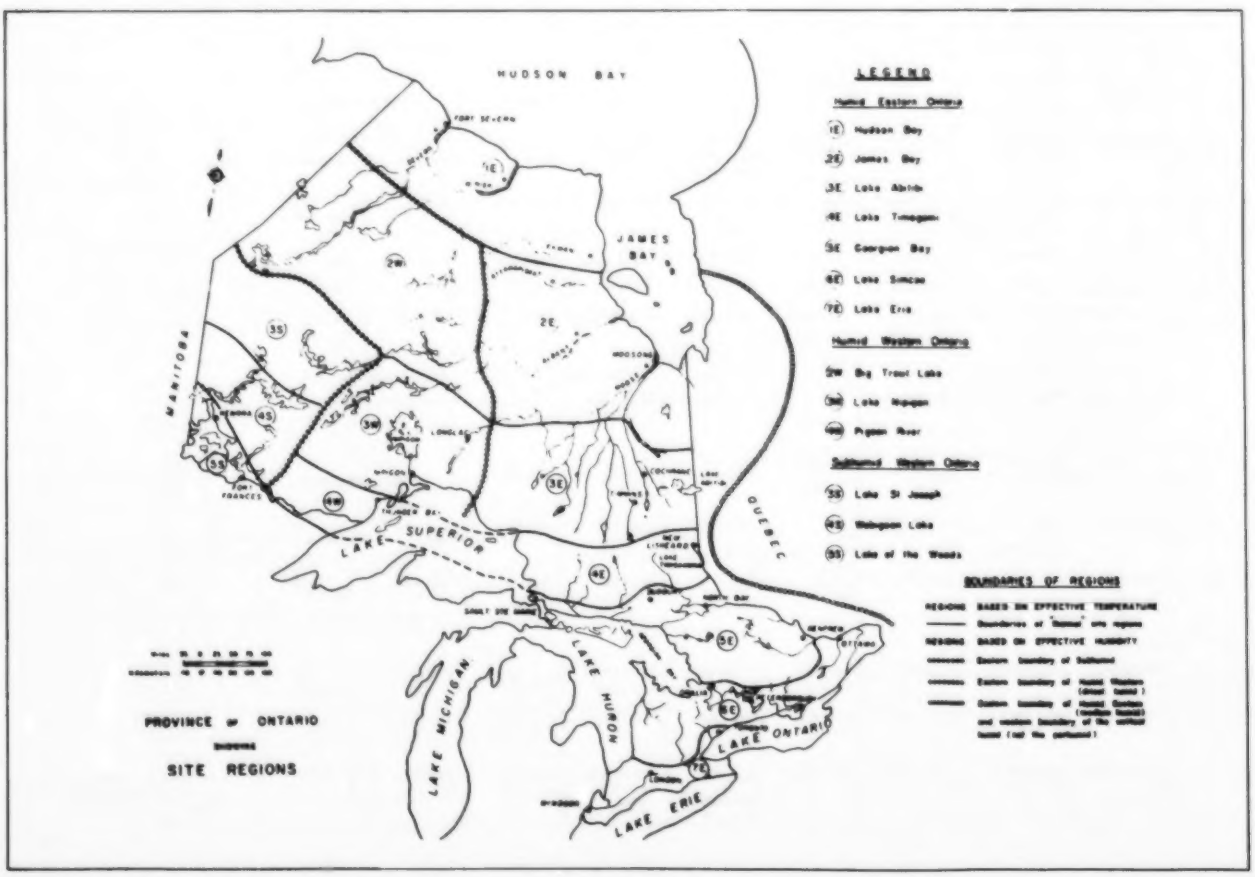


Figure 1. The site regions of Ontario (source: Hills 1966)

useful for large areas of land, the texture and petrography classes of these geological materials (Burger 1967, 1972a) are usually broader than those used in establishing catenas in agricultural soil surveys.

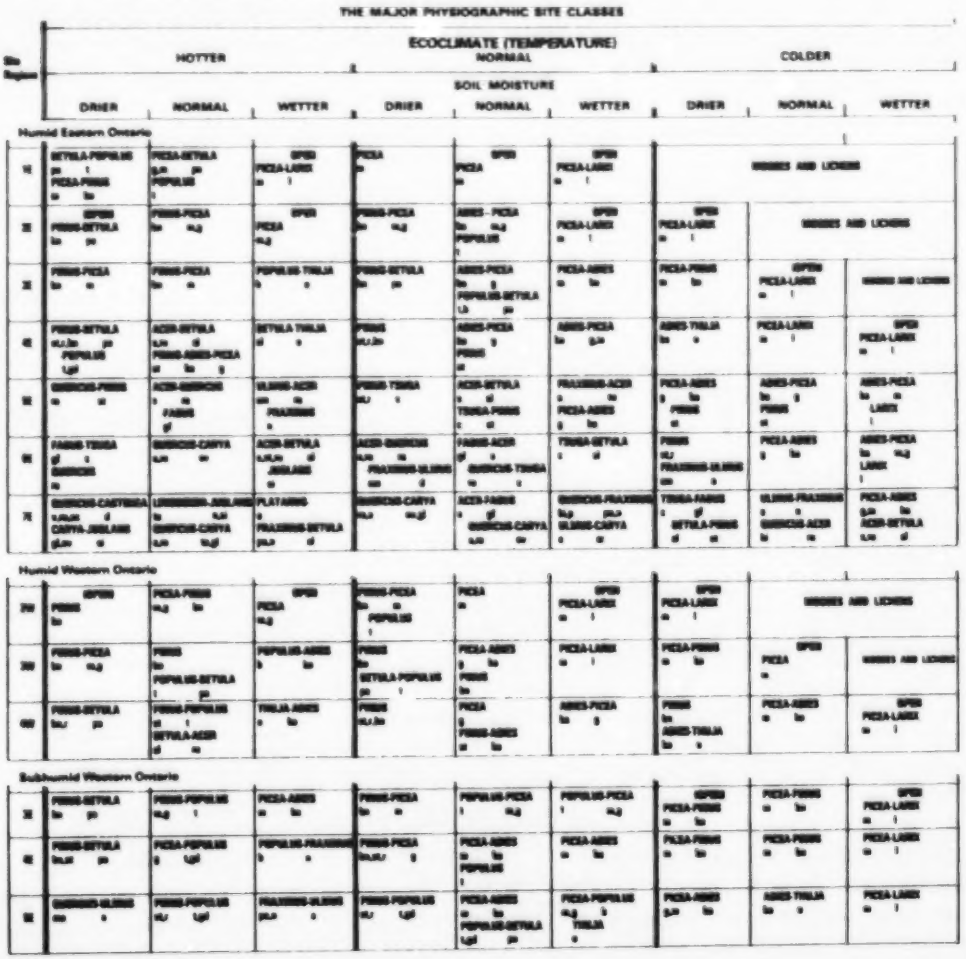
The third, and most important, level in the Ontario classification system is the 'physiographic site type', a subdivision of the 'land type'. It is defined by relatively narrow ranges in (i) depth of geological materials occurring in the rooting zone, (ii) soil moisture regime, and (iii) local climate. An example of a physiographic site type is: a dry shallow (30–120 cm), very low base (granitic), medium sand over a very low base bedrock, with a hotter than normal ecoclimate. The physiography/vegetation relationships studied at this level provide the basis for the establishment of site regions and the classification of significant land types. The ecosystem as defined by tree species and physiographic site type provides a convenient level to summarize descriptive information and ecological knowledge. This is the level at which the potential productivity is rated, and at which the forester usually has to manage his forest stand.

The fourth and last level is called 'site condition'; it refers to the forest floor and upper soil horizons. Variations in site conditions within any one particular physiographic site type reflect differences in history of forest growth and disturbance (eg fire and soil erosion), and influence both the actual forest production and the competition from undesired vegetation during forest establishment. Currently important 'forest ecosystem classification' programmes are in progress in northern Ontario (Jones 1984; Jones *et al.* 1983a,b). Extensive sampling of vegetation and soil, computer-based data analyses and modelling, and close co-operation between researchers and forest managers have resulted in the establishment of classes of mature forest ecosystems. These classes provide the basis for considering the results of past management activities, making interpretations and developing prescriptions for harvesting and related forest regeneration operations. These ecosystem classes may also serve fire management activities and wildlife management.

5 Mapping and evaluation

This Ontario site classification system – also called the physiographic site classification system because physiography is used as a basis for ecosystem ('total

Table 3 The characteristic forests of Ontario, simplified after Hills (1966)



ABBREVIATIONS

a alba
al alleghaniensis
am americana
b balsamifera
ba balsamea
bi bicolor
bn banksiana
c canadensis
cc coccinea
ci cinerea
cr cordiformis
d dentata
g glauca
gd grandidentata
gf grandifolia
gl glabra
l lancina
m mariana
ma macrocarpa
n nigra
o occidentalis
ov ovata
p palustris
pa papyrifera
pe pennsylvanica
r resinosa
ra rubra
ru rubrum
s saccharum
sa saccharinum
st strobus
t tremuloides
to tomentosa
tu tulipifera
v vetutina

Ont. Tree Improv. & Forest Biomass Inst.
Ministry of Natural Resources
Maple, Ont., Canada
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site') classification – provides the taxonomic units within which knowledge can be organized. However, land areas are not always sufficiently homogeneous to allow the mapping of single taxonomic units. Therefore, a number of broader units have been developed for mapping at several scales, each with fairly specific purposes in mind. These units include 'land type components' (scale 1 : 50 000) which are patterns of physiographic site types (Pierpoint 1962) useful for management operations, and 'land type pattern' at a scale of 1 : 125 000 (Burger 1972a) for broad forest land management planning. 'Land units', segments of landscapes each of at least 10 km^2, and the even larger 'landscape units' (Hills *et al.* 1970) comprising several land units were developed for multiple land use planning. Finally, a 'site district' (scale 1 : 4 000 000 to 1 : 10 000 000) is a subdivision of a site region based on a characteristic pattern of physiographic features, such as relief, type of bedrock, and soil parent materials.

For use in forest and land management, both taxonomic and mapping units have been evaluated with respect to potential production and degree of effort required to obtain a desired crop (Hills & Pierpoint 1960) and for rating forest use capability (Hills 1966). Site regions are used as seed zones and provide regional boundaries for silvicultural treatments.

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